Micro-manipulation of silicate micro-sized particles for biological applications.

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***Abstract*— There are great challenges in biological research to study mechanical or chemical interactions between biological objects and artificial parts, to analyse the biocompatibility of artificial materials and/or to increase knowledge about biological cells. Some interaction studies between cells and artificial objects require to positioning very small objects whose typical size is comparable with cell's size (typically 5-20 micrometers).**

This paper presents design, building and testing of a new micro-manipulation station able to grasp, transport and release ten micrometers objects. Devoted to an existing piezoelectric microgripper, innovative end-effectors in silicon have been designed after several mechanical studies. They have been built with microfabrication processes (DRIE[1]) in SOI [2] wafers.

For the application, the positioning of silicate crystals which contain iron close to E-Coli bacteria, new end-effectors were glued on the piezoelectric microgripper. Mounted on a three axis micropositioning stage under a videomicroscope, this innovative microgripper is able to grasp a silicate crystal of 15 micrometers in the air and release it in the bacteria liquid medium.

I. Introduction

Micro-manipulation is a feature key in micro-factories where micro-products are too small to be handled manually by an operator. To improve micro-assembly tasks, it is essential to create different kind of micro-manipulation cells which could be included in most micro-factories.

Many tasks could include micro-objects handling like pick and place, assembly, chemical process or mechanical caracterisation. Specially in biological domain, cells caracterisations are performed with a micro-force sensor [1] [2]. In particular, studying specific cells behavior in interaction with artificial objects could be used to determine their biocompatibility [3].

The aim of this paper is to present a new micro-manipulation station's design where artificial handled objects are smaller than 50 micrometers. In collaboration with the LST (Laboratoire de Sciences de la Terre, Lyon, France) a biological application has been chosen as a framework for the micro-manipulation station. Micro-sized particles of silicate have to be inserted in a liquid medium where E-Coli bacteria are living. bacteria behaviour around silicate particles will be studied with an inverted microscope.

The applicative objective is to drop one silicate micro-crystal near E-Coli bacteria in their liquid medium. Thus a micro-gripper is required to grasp one micro-crystal outside the liquid, bring it into and release it close to the biocells (see in figure 1).

[1]Deep Reactive Ion Etching, with a Bosch process
[2]Silicon On Insulator

II. Micro-manipulation Station

Micro-manipulation tasks are performed by an operator. He needs several views of the scene and an interface to control the station. To guarantee movements' precision, several micropositionning stages are used and a microgripper grasps the micro-objects. Schematic view of the station is presented figure 2.

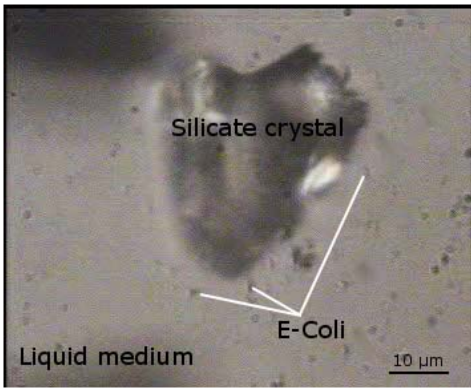

Fig. 1. E-Coli bacteria and silicate particles

A. Vision

One microscopic upper view is required to visualize the pick and place tasks. bacteria and crystals are smaller than 50 micrometers, so the view can't be larger than 1 mm. In fact, with a standard CCD camera of 640x480 pixels, this kind of objects is represented by enough pixels (1 pixel square fit to 1,5 μm^2 if the whole view is about 1 mm^2). For this view, a classic microscope is used, viewing the scene upward.

A side microscopic view can be used to see the vertical displacement of the gripper. A camera with a microscope zoom is sufficient for the pick and place tasks. Both views are fixed on the station holder, and the two optical plans of these views intersect on the aimed micro-object. As a result, operator will perceive the three dimensions of the scene.

B. Stages

Three micropositionning stages are disposed on the cartesian axis. X and Y stages of the horizontal plane are used to move the glass microscope slide supporting the liquid medium. The gripper can be moved only on Z axis, therefore gripper's end effectors stay always in the microscopic upper view. Thus it's possible to use a greater space for the micro-manipulation than the surface covered by the view (about 1 mm^2).

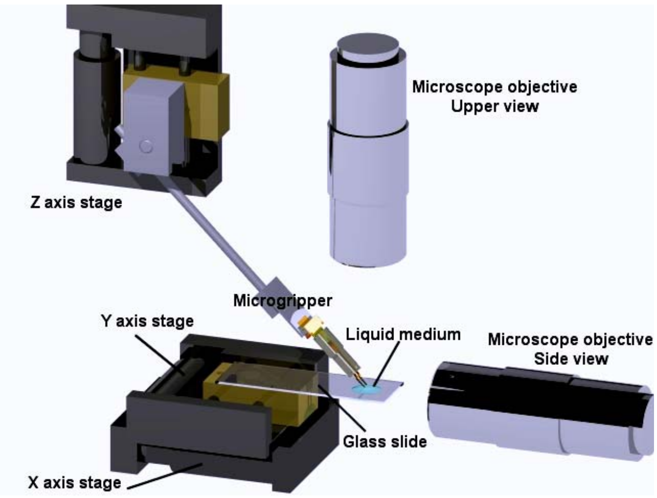

Fig. 2. Station setup

C. Microgripper

The microgripper used is based on the piezoelectric gripper, presented in [4], with new end-effectors. Each finger is able to move independently from the other in two orthogonal directions. This microgripper, named MMOC (Microprehensile Microrobot On Chip) has therefore 4 DOF[3] and is able to grip, hold, tilt and release submillimetric-sized objects (figure 3). The principle of one finger is based on a piezoelectric cantilever with local electrode, called *duo-bimorph*. Such microgripper presents a stroke of open/close motion and up/down motion of respectively, 320 and 400 micrometers at the end of the finger tips.

The MMOC is particularly innovative for the end effector assembly. In most microgrippers, actuator and end effectors are both made on the same element. The MMOC is composed of an actuator and a connection system to fix end-effectors. The two fingered piezoelectric actuator has two spatula where different kind of end-effectors can be fixed. A automated fixing system, with a removable thermal glue has already been studied [5]. For the present application, specific end-effectors able to grasp objects from 10 to 100 micrometers have to be designed.

III. End-Effector Design

The specific end-effectors have to be adapted for the manipulation in a biological medium of 50 micrometers or less objects. The design requires to define the material constraints associated to a biocompatible system, and the desired mechanical behavior and design to this kind of micro-manipulation tasks.

[3]Degree Of Freedom

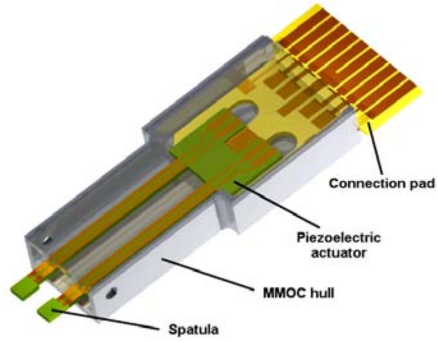

Fig. 3. Piezoelectric Microgripper MMOC

A. Material and Mechanics

As regards to the material of new end-effectors there are three parameters to take in account: the mechanical properties, the micromachining possibilities and the biocompatibility. First, piezoelectric actuator cannot be immersed and end-effector are glued to it with a water removable glue. Thus end-effectors must be sufficiently long to have its extremity fully immersed in the liquid medium and its basis safely in the air. Therefore capillary distance and depth of the liquid medium must be taken into account to define the end-effectors' length. Secondly, to manipulate micro-sized objects, end-effectors' width and height must be up to 100 μm, so microfabrication is the only way to produce this kind of mechanical part. Thus the material have to compatible with microfabrication process. Thirdly only biocompatible and water resistant material can be chosen.

Finally, only few material remain, and silicon is the more interesting for the new end-effectors. In fact, silicon in microscale have great mechanical features: its Young modulus is 20% lower than structural steel and its yeld stress is two to four times greater [6]. Moreover, its fracture strength is mainly close to 1,5 GPa [7] still for microscaled silicon cantilevers. At last, silicon is fully bio-compatible and water resistant, its oxyde SiO_2 is bio-compatible too.

B. Design

End-effectors' shape must be defined according to its main functions. The manipulation area has to be adapted to the micro-object size. In fact, with microscopical vision, the depth of focus is very thin (about few micrometers) and if the end-effectors are twice or more thicker than the grasped micro-object, it's quite impossible to see it. Minimum object size is 10 micrometers, therefore end-effectors thickness has to be close to this value.

End-effector grasping part must be sufficiently long to go through the liquid medium (about one millimeter). Further-more, end-effectors have to be mounted manually on the microgripper with the removable thermal glue. Width and thickness of the glued part is consequently close to 1 mm with a length of few millimeters. Finally, this end-effector design is composed of two thickness of silicon (close to 10 μm and 1 mm) and both parts, thin and thick, are few millimeters long. After several mechanical studies on the grasping part deformation during micro-manipulation, the final design has been defined (figure 4).

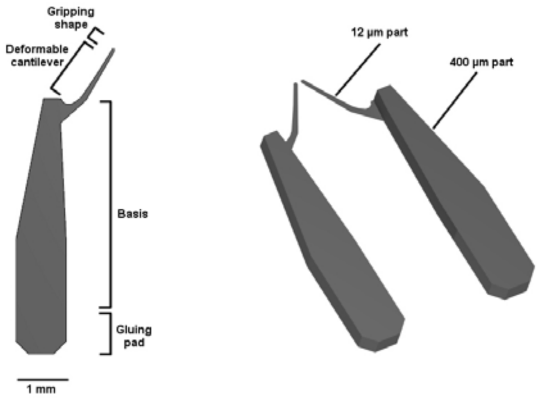

Fig. 4. New end-effectors design

To build the SiFiTs (Silicon Finger Tips), a micro-fabrication process wafer has been used with a special silicon wafer.

C. SiFiT Microfabrication

Silicon wafers used to build innovative end-effectors are Silicon On Insulator wafers (SOI) composed of three layers: 12 μm and 400 μm of monocrystal silicon separated by 1 μm of silicon oxide. The main interest is to allow dry etching of both silicon layers to make specific tools.

SiFiTs have been made using classical microfabrication process. After photolithograpy on both wafer sides, aluminium layers have been wet etched to draw the desired shape on it. Bosch Deep Reaction Ionic Etching (DRIE) process was used to cut SiFiTs in silicon wafer. Moreover, innovative breakable parts have been studied and added to this wafer, specially devoted to separate manually end-effectors from the wafer support [8].

An alignment part was created to keep the two fingers aligned before fixing on the MMOC. After the end-effectors fixing process, this alignment part is removed by means of its two breakable parts (figure 5).

IV. Experiments

A. Mounting process

Silicon Finger Tips needs to be glued on the MMOC to get it fully operational. A mounting station has been designed to allow manual fixing of these end-effectors after several thermal and mechanical simulations. A thin aluminium part is combined with a thermal resistor to liquefy the glue. Both are thermally isolated from the mounting system's support by two glass slides. With a thermal power of 10 W, aluminium slide go from 25°C to 90°C in one minute (melting temperature of thermal glue is close to 70°C). A mounting station has been designed to allow manual fixing of these end-effectors after several thermal and mechanical simulations. A thin aluminium part is combined with a thermal resistor to liquefy the glue. Both are thermally isolated from the mounting system's support by two glass slides. With a thermal power of 10 W, aluminium slide go from 25°C to 90°C in one minute (melting temperature of thermal glue is close to 70°C).

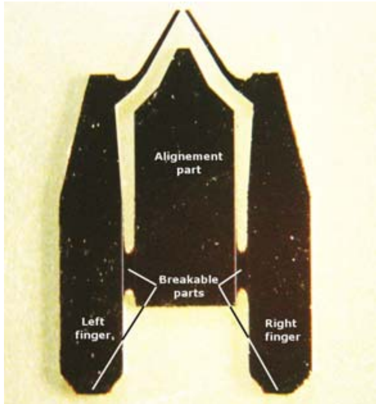

Fig. 5. Silicon Finger Tips - Before microgripper mounting process

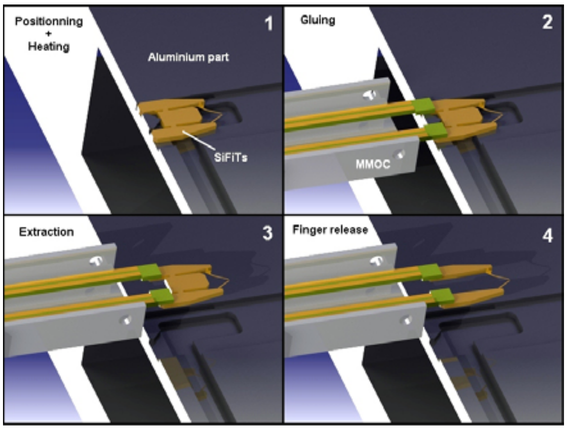

Fig. 6. Microgripper mounting process

SiFiTs pair is separated from the wafer by means of the breakable parts and this block (SiFiTs and alignment part) is position on the aluminium part (figure 6 - case 1). Then resistor is powered up and glue is disposed on SiFiT's pads. When aluminium part's temperature reaches the glue liquefaction temperature, MMOC spatulas are manually positioned on them and the resistor is powered down (figure 6 - case 2). After glue solidification, MMOC and SiFiT are both extracted from the imprint (figure 6 - case 3) and finally the alignment part is removed to release the fingers (figure 6 - case 4).

B. Micromanipulation Station

Micromanipulation station has been built to perform experiments of pick and place of silicate micro-crystals and other micro-manipulation tasks. Two screens show microscopic views and a computer is dedicated to the human station interface and both stages and microgripper control. A joystick allows manual control of the station by human operator. With this joystick, the operator controls the 3 DOF of the station and the 4 DOF of the gripper.

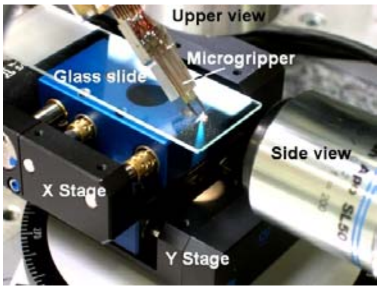

Fig. 7. Focused view of the micro-manipulation station

C. Silicate crystals micro-manipulation

Pick and place tasks of silicate crystal have been performed with a great reliability. Silicate crystals from 10 to 100 micrometers have been grasp in the air, brought into the liquid medium and released into.

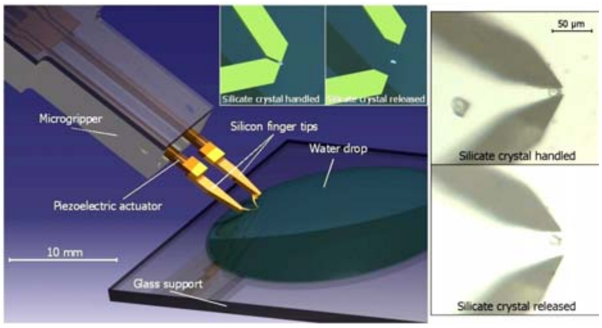

Fig. 8. Silicate crystal micromanipulation (virtual and real)

Several observations during the manipulation have to be underlined. First, adhesive forces between crystals and SiFiTs are the most disturbing element of the micro-manipulation. As currently described in the literature smaller the crystal is and harder the release is. However, with the MMOC's 4 DOF, the operator can scrape the crystals with the end-effectors and most are finally released. Secondly, SiFiTs are quite much elastic and robust, so when the operator is touching the glass support, they bend very quickly. Moreover, they bend too during the grasping. Therefore, it's easy to estimate grasping forces during the micro-manipulation. Thirdly, many release tests have been carried out in the liquid medium and far from the glass slide for the minimum bacteria disturbing. In fact, it is better to release the crystal directly after water insertion at few hundred of micrometers from the glass slide. As a result, crystals sedimentations were quite vertical, and in most of cases, crystals were positioned with a precision of 20 micrometers.

V. Conclusion and Further Works

An innovative micro-manipulation station able to grasp micro-objects of 10 to 100 μm was presented. New end-effectors have been designed, built and tested. The MMOC microgripper, was used in this new station and combined with innovative end-effectors. As a result, many experiments have been made with success on silicate micro-crystals and lots of observations about SiFiT behaviour have been underlined.

Further works will done on the improvement of the micro-manipulation station. Using of liquid medium can be brought into widespread use for artificial micro-objects, specially in micro-assembly tasks [9]. SiFiTs can be improved to integrate many functions like force-sensing, electrostatic actuation [10], etc.

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References

[1] D. Nishi,T. Arai, K. Inoue, T. Takubo, *Measurement of the Mechanical Properties of Living Cell Using Micro Hand and developed AFM System*, IEEE RSJ International Conference on Intelligent Robots and Systems, 2005, pp. 1184-1189.

[2] M. Boukallel, M. Girot, S. Regnier, *Haptic Rendering of Biological Elastic Properties based on Biomechanical Characterization*, in Proc. of the IEEE/RSJ Int. Conf. on Intelligent Robots and Systems, Beijing, China, 2006.

[3] K. Wan, *Incorporating Solid Mechanics into Biomedical and Life Sciences*, Journal On Mechanics, July 2006, pp. 42-47.

[4] P. De Lit, J. Agnus, C. Clévy, N. Chaillet, *A four-degree-offreedom microprehensile microrobot on chip*, Assembly Automation, Vol. 24 No. 1, 2004, pp. 33-42.

[5] C.Clévy, A. Hubert, J. Agnus and N. Chaillet, *A micromanipulation cell including a tool changer*, J. Micromech. Microeng, Vol. 15, 2005, pp. 292-301.

[6] Cambridge University Engineering Departement, *Material Data Book*, 2003, pp. 9-12.

[7] K. S. Chen, A. A. Ayon, X. Zhang, S. Mark Spearing, *Effect of Process Parameters on the Surface Morphology and Mechanical Performance of Silicon Structures After Deep Reactive Ion Etching (DRIE)*, Journal of Electromechanical Systems, Vol. 11 No. 3, June 2002, pp. 264-275

[8] D. Hériban, J. Agnus, J.R. Coudevylle, M. Gauthier and N. Chaillet, *Design of Silicon Finger Tips for a MOC (Microrobot On Chip) Microgripper*, In Proc. of 1st Topical Meeting on MicroFactories (TMMF2005), pp. 47-52, Tsukuba, Japan, October 2005.

[9] M. Gauthier, D. Hériban, D. Gendreau, S. Regnier, N. Chaillet and P. Lutz, *Micro-factory for Submerged Assembly: Interests and Architectures* in Proc. of the IEEE International Workshop on Micro-Factories, Besançon, 2006.

[10] E. Gibeau, M. Gauthier, D. Hériban, emphSubmerged Robotic Micromanipulation and Dielectrophoretic Micro-object Release in Proc. of the IEEE Int. Conf. on Control, Automation, Robotics and Vision , Singapore, 2006.